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A review of climate change impacts on commercial buildings and their technical services in the tropics

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ABSTRACT

Climate observations in recent years indicate that the effects of climate change events are apparently having an increasing impact on society. These impacts will likely also affect the building sector. Numerous studies have been conducted to assess future building energy consumption rates. However, these studies often do not take into account climatic variability and consumer reactions towards a temperature shift. A literature review on climate change impacts for commercial buildings and their technical services in the tropics was carried out. This review focuses on the buildings' contributions towards climate change as well as climate change impacts on building structures, changing patterns of energy use and peak demands, building heating and cooling requirements, thermal comfort and emissions impacts. In general, buildings in regions with a predicted increase in temperature will need more cooling and less heating loads. Thus, building energy consumption and carbon emissions are projected to rise during its operational phase. In addition, the erratic weather trends will also affect the building efficiency and sustainability, indoor air quality and thermal comfort. Even though the existing literature on this issue has increased substantially in recent years, there is still a need for further research in tropical climates as the climate change impacts vary with the different seasons, periods and regions.

Contents

1. Introduction

Based on the strong evidence of global warming trends affecting average air temperatures and composition of greenhouse gases, a vast number of studies on climate change impacts on diverse aspects of human life, such as economy, health, energy, water resources, politics and agriculture, have been conducted. The third assessment report Work Group (WG) II [1] acknowledged that *"The basis of research evidence is very limited for human*

Abbreviations: CBECS, Commercial Building Energy Consumption Survey; HVAC, Heating, Ventilation & Air Conditioning; CFCs, Chlorofluorocarbons; HVAC&R, Heating, Ventilation, Air Conditioning & Refrigeration; DD-NEMS, Degree-Days- National Energy Modeling System; IPCC, Intergovernmental Panel of Climate Change; DBT, Dry Bulb Temperature; PIER, Public Interest Energy Research; GCM, Atmosphere-ocean general circulation models; WBD, Wet Bulb Depression; HCFCs, Hydrochlorofluorocarbons; WBT, Wet Bulb Temperature

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settlement, energy and industry. Energy has been regarded mainly as an issue for Working Group III, related more to the causes of climate change than to impacts. Impacts of climate change on human settlements are hard to forecast, at least partly because the ability to project climate change at an urban or smaller scale has been so limited. As a result, more research is needed on impacts and adaptations in human settlement".

Inferring from this, the building sector appears to be vulnerable to challenges from climate change, especially global warming. The potential implications of increasingly extreme weather patterns such as winter storms, droughts, flooding, earthquakes and storms introduce various challenges for buildings. Global warming is anticipated to have strong implications on future energy demand of buildings, in particular, with regard to the overheating aspect. The third assessment report of the Intergovernmental Panel on Climate Change (IPCC) [1] summarized the implications of climate change on the building sector as" *increased electric demand and reduced energy supply reliability".* Many studies have been carried out to predict building energy consumption in the future. However, these studies generally do not consider the impacts of temperature swings on building energy consumption due to climatic variability. From the perspective of climate change impacts, the building sector ignores the climatic variability and the consumer reaction towards temperature change, such as increasing usage of air conditioning and natural ventilation to improve thermal comfort.

In fact, climate change is predicted to have strong effects on a building's energy requirements as their heating and cooling needs are highly related to temperature conditions and weather variations. Current weather files for building performance simulations are commonly derived from historical data for the period 1961–1990, which does not reflect climate trends or future climate projections. Therefore, it is important to study the implications regionally as different climate change effects are expected in different countries, seasons and periods.

The building sector in Malaysia consists of commercial, government, and high-rise residential buildings. The energy consumption in this sector in 2008 was about 7750 GW h per year [2]. With the increase in new building construction and inefficient energy utilization in existing buildings, the annual energy consumption in this sector is expected to rise over the next few years. If its overall energy utilization performance does not improve, this sector will continue to contribute significantly to the national greenhouse emissions of gases. For instance, in 2008, the building stock in the country amounted to about 37.81 million m^2 per area, of which 11% of the buildings were considered as Energy Efficient buildings (the Building Energy Index of which is 136 kW/m^2 and below). In the same year, this sector emitted about 5301 ktonnes carbon into the atmosphere [2].

Buildings designed according to existing standards may become increasingly costly to operate and maintain in the future. Increases in wind speeds and extreme weather events, temperature swings, changes in levels of precipitation and relative humidity should be taken into account to ensure that current and future buildings are able to adapt to these changes and thus minimize the potentially destructive impacts, such as energy use and carbon emissions.

Therefore, this review will concentrate on climate change impacts on buildings and their technical services in the tropics. Recently, the effects of erratic weather patterns on building energy requirements and use have been widely discussed internationally. However, literature review reveals that only a few studies have focused on the regional impacts, especially in the tropics [3–90]. Essentially, a general relationship between temperature conditions and variations with heating and cooling demand, energy use and peak demand, carbon emissions, and building's sustainability will be detailed and summarized in this review.

2. Climate change

Only about a decade ago, global warming and climate change were just a hypothesis. However, now the global warming and extreme weather events are being recognized as leading the changes in global climate. In Asia, these events can be seen as, increased flooding in Malaysia and droughts in Australia, while in Europe, there are events such as increasingly intense summer heat waves, melting glaciers and rising sea levels. At the poles, there is an increased melting of Arctic ice and permafrost. All of these phenomena are potential signs of increased warming.

Currently, we experience much warmer summers, colder winters and frequent extreme weather events, which indicate an acceleration of atmospheric warming. Cases of heavy precipitation have become more frequent with the increase in the atmospheric vapor. Eighty percent of the additional heat in the climate system has been absorbed by the ocean since 1961 and since then, the ocean temperature has risen down to depths of 3000 m. During 1993–2003, the sea level has risen up to 3.1 mm per year due to the losses from the land-based ice sheets of Antarctica and Greenland [3].

Bader [4] in his study disclosed that there was an abrupt drop from high summer to low winter temperatures, resulting in extremely cold weather in October 2003. In a separate study in the following year, Luterbach et al. [5] concluded that 2003 was the hottest summer, and 1709 was the coldest European winter. If we remember, the summer of 2003 caused many fatalities. For instance, France alone recorded nearly 15,000 deaths above average for the season, and these were directly related to nights during which the temperature did not drop below 29 °C. Another study by Shar et al. [6] went to a step further and found that the increase in average temperatures, were responsible for the summer heat waves in 2003. These studies imply that adaptation to climate change should be planned in advance to prevent further fatalities in the future.

Climate change by definition is a climate shift due to human activities modifying the proportion of natural greenhouse gases in the lower atmosphere. Over the centuries, researchers all around the world have been debating the causes of climate change. Climate change occurs mostly due to the economic development and human actions prior to modern life. Generally, there are three spheres of climate change impacts, the primary (wind speeds, floods, extreme climatic events, temperatures, driving rain), secondary (variations of plants and animals) and tertiary (community, institutional, behavioral) sphere. Naturally, the earth's climate depends on its natural greenhouse gases. The heat radiated from the lower atmosphere is absorbed by these gases, which radiate most of it back towards the atmosphere surface. The earth would be approximately 18 °C colder without the existence of these natural greenhouse gases.

Generally, global warming is due to natural and anthropogenic forces. Simulations based on the historical global climate show that natural forces, such as the tilt of the earth's axis, alone could not produce the warming recorded over the past 40 to 50 years. Eventually, both of these forces have produced the observed climate change phenomenon. The main cause of the anthropogenic force is undoubtedly the rise of greenhouse emissions of gases.

The IPCC Second Assessment Report [7] states the possibilities of opposing effects of the human influence on global climate change, such as the increase in carbon emissions into the atmosphere. The proportions of carbon, methane and nitrous dioxide in the atmosphere have been increasing since the Industrial Revolution in the 18th century (Fig. 1), causing the natural greenhouse effect to intensify and resulting in changing the earth's climate. Carbon dioxide produced by burning of fossil fuel and methane

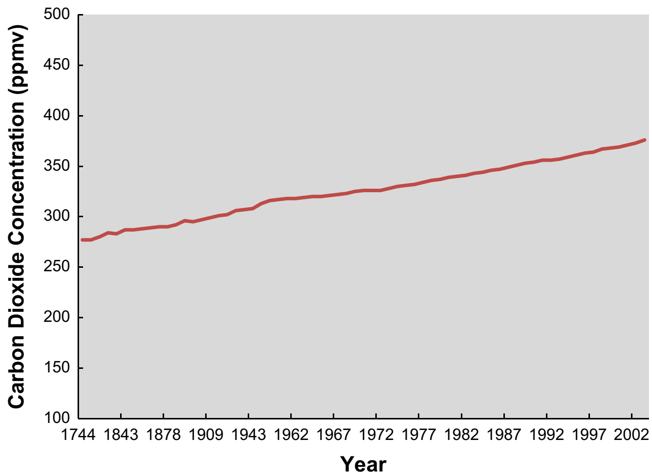

Fig. 1. Global carbon dioxide concentration (parts per million by volume) [91].

released from agricultural activities are trapping heat in the troposphere zone, hence increasing the warming effects even further. In contrast, aerosol emissions such as sulphates produce cooling effects in the lower atmosphere. In 1992, the proportion of carbon (CO_2) emissions in the atmosphere significantly increased by 30%, nitrous dioxide (N_2O) by 15% and methane (CH_4) by 14% [1].

2.1. Climate change scenario

Predictions of climate change for the next 100 years are typically associated with the term scenario rather than the term prediction. Several uncertainties must be considered during the interpretation of future climate prediction, such as the unknown factor of the actual climate system's response to the changes in the atmospheric concentrations, socioeconomic advancements and carbon emission scenarios. On the other hand, for the quantitative evaluation of the effects of the climate shift on building operations, the regional climate variability must be considered.

For the past 10 years, the Intergovernmental Panel on Climate Change (IPCC) has put substantial effort into characterizing the possible effects of carbon emissions produced by daily human activities. The IPCC has been concentrating on developing an *atmosphere-ocean general circulation model (GCM)*, which is comparable to the model employed for weather forecasting. In this model, the equations are derived based on the physics of the atmospheric motion, which are solved by advanced computers. A high level of spatial resolution (5×5 degrees longitude and latitude) [3] is anticipated in the GCM. The main GCMs are *CSIRO2 (Australia)*, *HadCM3 (United Kingdom)*, *PCM (US)* and *CGCM2* (*Canada*) [8].

The IPCC Work Group (WG) III has developed major storylines, which correspond to the possible variations of diverse social, demographic, environmental, technological and economic progress. Four emission scenarios from the storylines, which reflect the range of potential climate change effects as defined by the IPCC, are [9]:

i. A1 scenario family: rapid population and economic development, three groups of alternative energy system change: fossil intensive, non-fossil resources or balance between sources
ii. A2 scenario family: continuous population growth but fragmented economic growth
iii. B1 scenario family: population peaks in mid 21st century; economic change towards service and information economy, clean and resource-efficient technologies at global level
iv. B2 scenario family: a local solution to economic, social, environmental sustainability; intermediate population and economic development.

When combined within the GCM, the scenarios represent a range of potential climate impacts resulting in 16 combinations of climate predictions and scenarios.

Due to the increase of carbon emissions, the global average surface temperature has also risen since 1861 (Fig. 2). This is no surprise since the Earth has been warming continuously over the last 12,000 years since the last major ice age glaciations. The increase in global average temperature is the parameter that obviously indicates incremental warming. In the IPCC Fourth Assessment Report (AR4), the global average temperature has increased up to 0.74 °C since the 18th century. Additionally, the Third Assessment Report of the IPCC [8] predicts that over the period of 1990–2100, the global mean surface temperature will increase by something in the range of 1.4 °C to 5.8 °C, and extreme weather events will become more frequent. There will also be an increase in temperature of up to 3.5 °C with the uncertainty of ± 0.2 °C for different climate settings in the year of 2100 relative to 2000. Based on observations, 1996 was the

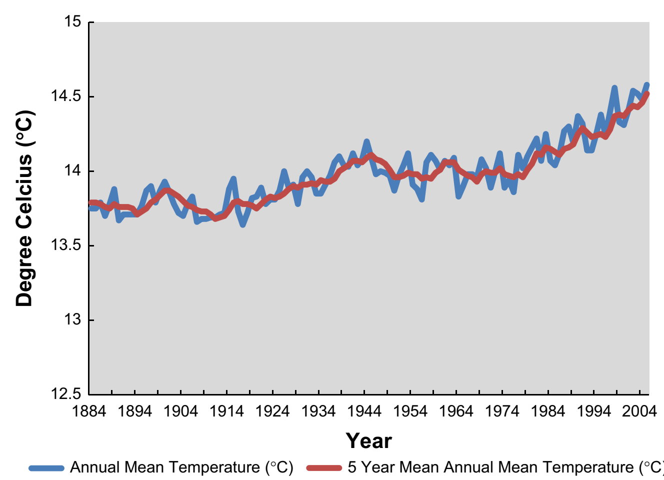

Fig. 2. Mean global surface temperature 1880–2005 [91].

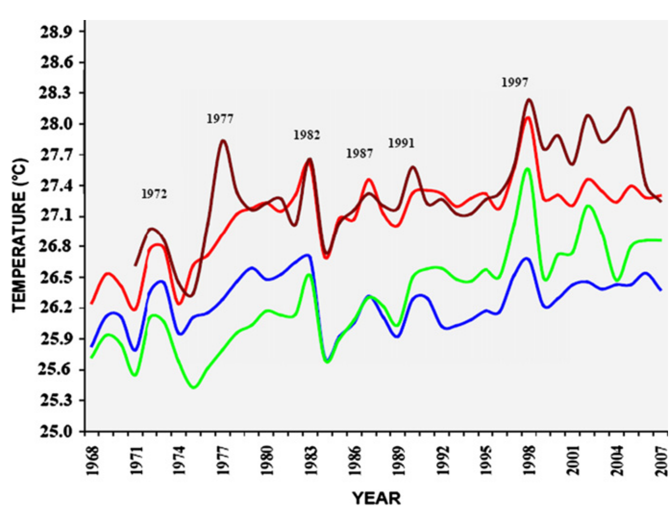

Fig. 3. Seasonal mean temperatures for Peninsular Malaysia and East Malaysia, respectively [10].

single warmest year during the 147 year period of recording, and 1995–2007 were among the top 12 warmest years.

In Malaysia, climate change is determined by the mountainous topography and complex land–sea interactions. For the past 40 years, there has been an increasing temperature trend in Malaysia. According to the data obtained between 1961–1990 and 1998–2006 (Fig. 3), Peninsular Malaysia has experienced a much higher temperature rise (0.5 °C to 1.5 °C) compared to East Malaysia (0.5 °C to 1.0 °C) [10].

According to the Malaysian Meteorological Department, the annual average temperatures are projected to rise in 2028, 2048, 2061 and 2079. The highest temperature rise for Peninsular Malaysia is 3.7 °C (December–February), Sabah 4.1 °C (March–May) and Sarawak 3.9 °C (March and May) [10]. Based on the simulation of predicted temperatures for three emissions settings (A2, A1B and B2), the highest (obtained in A2 simulation) and lowest values (obtained in B2 simulation) of the annual surface temperature varies between 2.3 °C and 3.6 °C for Peninsular Malaysia and 2.4 °C to 3.7 °C for East Malaysia.

Based on the climate change projections in the UK, the average warming per decade was expected to rise between 0.1 °C and 0.3 °C for the low emission setting and 0.3–0.5 °C for the higher emission setting [11]. Related to this, winters are anticipated to become wetter and summers to become hotter and dryer. By the 2020s, the frequency of wetter winters is likely to rise to 15% and by the 2050s, the frequency will increase to 25%. Meanwhile, by the 2080s, the number of cooling degree days is predicted to rise by twofold in the south of the UK [12]. In the Third Assessment Report, it has been estimated that the area-averaged mean warming over the land regions of Asia will rise by 3 °C in the 2050s and by 5 °C in the 2080s [8]. Related to this, the temperature rise would likely be notable across Asia during all seasons.

Research conducted by the Hadley Centre in the UK [13] proposed that the average global temperatures across Europe will rise by up to 2.4 °C and 5.4 °C over the next century due to the high greenhouse emissions of gases. Up to 2005, the carbon concentration in the lower atmosphere has risen dramatically from 280 ppm to 380 ppm. During pre-industrial times, the rise of greenhouse gas concentrations due to the increase of temperature was approximately 450 ppm carbon dioxide Eq for 2.1 °C, 550 ppm for 2.9 °C, 650 ppm for 3.6 °C, 750 ppm for 4.3 °C, and 1000 ppm for 5.5 °C. According to the predicted emissions of carbon dioxide based on various emission scenarios, the highest carbon dioxide concentration was obtained in the A2 scenario compared to B2 and A1B. Based on current practices regarding fuel type usage and socio-economic activities, the carbon concentration in the A1B scenario increased from 350 ppm to 700 ppm by the year of 2100.

3. The contribution of buildings to climate change

The fourth assessment report of the IPCC (AR4) acknowledged that since 1750, the proportion of carbon emitted to the global atmosphere has been rising primarily due to human activities. Nowadays, in developed and developing countries, buildings are accountable for more than 40% of global energy consumption and approximately 30% of global greenhouse emissions [3]. The most important elements in the emission scenarios considered in the building energy consumption are the carbon emissions and the environmental implications. Many commercial buildings are responsible for up to 200 t of carbon emissions per square meter of floor space due to the electricity consumption during the operational phase [3].

In absolute terms, the fourth assessment report of the IPCC (AR4) estimated building related carbon emissions to the amount of around 8.6 million metric tons of CO_2 equivalent in 2004 [3]. Carbon emissions by definition describe the carbon dioxide emitted directly or indirectly by an activity. The main sources of these emissions are the combustion of fossil fuels for cooling, heating, and lighting purposes, and to power electrical appliances. The building sector is also accountable for significant amounts of non-CO_2 greenhouse gas emissions such as halocarbons, chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) due to their applications in cooling, refrigeration and, in the case of halocarbons, insulation materials. In 2004, it was estimated that buildings were responsible for approximately one third of global greenhouse gas emissions related to CO_2 and 60% of halocarbon emissions [3].

The electricity consumption and emissions by commercial buildings are anticipated to increase by 2.5% per year [3]. Buildings are responsible for a substantial proportion of energy-related emissions when emission footprints and life energy cycles are taken into consideration [14,15]. Generally, the greenhouse emissions of gases originated from the on-site combustion of fuels for heating and from the electricity used for cooling, heating and power supply in the buildings. Among the factors that contribute to the buildings' emissions are building design, building envelope, on-site distributed generation, energy end use in the building, lighting, air-conditioning, space heating and ventilation [16].

As buildings contribute generously to energy usage and carbon emissions, Pérez-Lombard et al. [17] in their review paper believe that buildings should be considered separately and become the third main sector in energy consumption, which can be divided into domestic and non-domestic buildings. Energy consumption in buildings comprises a significant proportion of the services shared with the other main sectors such as transport and industry. The increase in buildings' energy use to the level of transport and industry is due to the enhancement of building's technical services, growth in population, increasing demands on comfort levels as well as the rise in time spent inside buildings [18].

Obviously, the buildings' operational phase consumes the largest fraction of their energy use. Mechanical systems such as air conditioning have permitted the development of unique building types that rely on high-energy input for their normal operation, which is different to traditional buildings. Nowadays, most of the high-rise building depends on the mechanical user transportation systems such as elevators and pumps to raise water to high levels. In addition, deep plan office buildings require air conditioning, artificial lighting, and ventilation as the main part of the space is distanced away from the façade. Buildings with shells of glass and steel are unable to adjust their inner climates without excessive air conditioning usage, especially in dry and humid climates [19].

According to the recent studies, the buildings' operational phase produces approximately 80% of carbon emissions to meet several energy requirements for heating, cooling, lighting, ventilation and other electrical appliances [20]. Pérez-Lombard et al. [17] in their review addressed the fact that heating, ventilation and air conditioning (HVAC) systems in developed countries are responsible for 50% of energy consumption in buildings and 20% of the total national energy consumption. Additionally, Kwok and Rajkovich [14] also reported that in the United States (U.S.), nearly 40% of the amount of principal energy needs is consumed by buildings, of which 34.8% is used for HVAC equipment. The environmental impact of HVAC equipment is caused by the usage of electricity, water, refrigerant and embodied energy.

Overall, the space conditioning accounts for 30% of the energy use in the U.S. commercial sector and approximately 14.3% of all energy used in the U.S. is used for space conditioning in commercial buildings. In commercial buildings, lighting uses approximately a

quarter of the energy consumed, HVACR uses about 42% and the remaining amount is used by electronic equipments. All in all, HVACR energy use in commercial buildings currently represents over 6% of the total country emissions in the U.S, 4% of approximately 21 Metric tonnes (Mt) of total country emissions in Australia and 1–2% of total country emissions in India. However, in the case of India, this percentage is increasing extremely fast due to the increase in electricity demand in commercial buildings there [21].

The energy consumption during the operational phase of a building depends on several interconnected factors, such as climate and location, level of demand, supply, and source of energy, function and use of the building, building design and construction materials, and the level of income and behavior of its occupants. Climatic conditions and the type of environment in the building affect every aspect of a building's energy consumption over its lifetime. More significantly, the level of greenhouse gas emissions from buildings is directly related to the level of demand, supply and source of energy. In 2009, the buildings' operational phases consumed almost 77% of all the electricity produced at power plants in the U.S., while in Japan, the average annual energy consumption during the buildings' operational phase was determined to be 1.21 GJ/m^2 and their average annual carbon emissions were about 87 kg/m^2 [22]. Rosselló-Batle et al. [23] addressed that the carbon emissions due to the electrical consumption are much higher compared to diesel and gas. From observations made from a sample of 31 hotels, 81.6% of the carbon emissions were found due to the electricity consumption. The large factor of carbon emissions in the electric generation system in the Balearic Islands is accountable for these results.

Other factor that contributes to the production of the greenhouse gases is the generation of electricity itself. At the global level, it has been estimated that in 2004, direct combustion of energy from fossil fuels in buildings has discharged approximately 3 Giga tonnes (Gt) of CO_2 compared with 8.63 Gt of CO_2 per year from all energy end users [3]. Generally, buildings can be categorized into residential and non-residential buildings. In most countries, the residential sector is accountable for the greatest fraction of total primary energy use. Nevertheless, the energy consumption in non-residential buildings such as offices, public buildings and hospitals is also significant and growing.

Currently, the U.S. commercial and residential buildings consume approximately 3800 quadrillion BTU of principal energy, including the losses during electricity production, which emits approximately 0.6 Gt carbon [24]. In Canada, the total of energy use in the building sector was 614 TerraWatt hours (TW h) in 1999 and contributed more than 10% of Canada's total carbon emissions (approximately 699 Mt CO_2 equivalent greenhouse gas emissions). In the same year, the total emissions from this sector were 71.9 Mt; 43 Mt (60%) from the residential sub-sector and 28.9% (40%) from the commercial and institutional sub-sector [25].

In Brazil, the building sector, which includes the commercial, residential and public services, is accountable for approximately 20% of the total energy use and for about 42% of the electricity use. In total, the residential sector consumes 23% of the country's electricity while the non-residential sector is responsible for 19% of the consumption [26]. On the other hand, in the low-income countries such as sub-Saharan Africa, the residential sectors consume as much as 56.2% while commercial sectors only consume 2.2% of the total energy use [27].

Similarly, buildings in China are liable for 42% of the energy consumption, where the commercial sector covers about 8%, while the residential sector alone covers the remaining [28]. In India, the electricity consumption stood at 587 billion kW h in 2006, where 8% was being used by the commercial sector and 25% in the residential sector. Commercial buildings use 32% of the electricity consumption for air conditioning, 60% for lighting and 8% for other equipment. Emissions in the commercial sector in that year can be estimated between 11 and 14 Million Metric tonnes (M Mt) due to the implementation of mechanical ventilation [21].

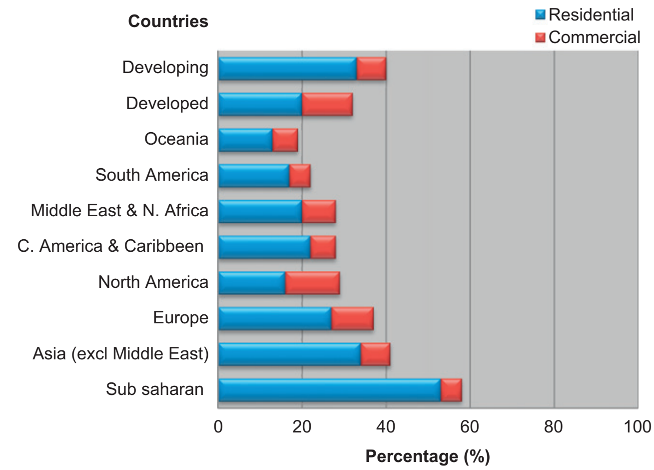

Fig. 4. Percentage of energy use in commercial and residential buildings in the world [92].

Meanwhile, in the ASEAN region, commercial buildings are accountable for 30% of all the electricity use and will demand approximately another 40% of generation capacity in years to come [29]. In 2004, commercial buildings in Malaysia were accountable for 75% of total national energy consumption while the residential buildings accounted for 44%. Typical office buildings in Malaysia use more than 260 kW h/m^{2}of energy per year and are responsible for almost 21% of the total national commercial energy consumption [30]. Related to this, office buildings' energy consumption is estimated to be around 6090 GigaWatt hours (GW h). The main energy users in office buildings are air conditioners (57%), lighting (19%), pumps and lifts (18%) and electrical appliances (6%) [31]. Building energy consumption of different countries and building sectors are summarized in Fig. 4.

4. Climate change impacts on buildings and their technical services

The typical life span of a building is estimated to be from around 60 to more than 100 years, thus the implications of different climate change scenarios on buildings should be considered in advance to enable society to adapt to these changes in the future. Historically, variations in regional climate have significantly affected the buildings' performance across the world. Numerous studies have been carried out to estimate the impacts on buildings and their technical services under the changing climates. Most of these studies have focused on analyzing the climate change effects on energy consumption, electricity and related greenhouse gas emissions. Until now, few studies have concentrated on the potential impacts in tropical regions, especially in Malaysia, Singapore, Southern Thailand, Brunei and Indonesia.

4.1. Climate change impacts on building sustainability and indoor environmental quality

Undoubtedly, climatic variability has led to physical damage to building structures. For instance, buildings are exposed to faster degradation and damage due to the increase in wind speed, level

of precipitation, long exposure to sun and temperature changes [32]. In addition, some parts of the building external envelopes are subjected to extensive degradation across Europe due to the long exposure to ultraviolet radiation and increased frequency of frost occurrence. According to Lisa [33], during the New Year's Day in 1992, the hurricane in northwestern Norway caused damages to buildings, which cost nearly NOK 1.3 billions, while several buildings collapsed due to heavy loads of snow throughout Northern Norway during the winter of 1999–2000. Additionally, most of the buildings in Eastern and Southern Norway were badly damaged due to heavy rainfall over long periods during autumn.

Another study conducted by Graves and Philipson [34] addressed the fact that the sustainability of building envelopes was badly affected by the increases in driving rain quantities and the frequency of intense weather events in several parts in England, which in turn, increase the buildings' maintenance costs. This study indicates that the cost of repairing damaged buildings due to the increase in wind speeds by 6% adds up to approximately £1–2 billion [35]. Higher wind velocity, increase in precipitation and frequent temperature changes could weaken the buildings' structure, loosen the roofing, and cause damage to the cladding, overhead electric and telephone connections. Wind driven rain in combination with increased in precipitation and wind loads amplified the weathering of high rise buildings [36]. Spence et al. [37] found in their study that an increase in wind speed from 40 m/s to 45 m/s would increase the number of damage incidents by a factor of five. Typically, older buildings are more vulnerable to wind damage. There are other cases in Denmark, which prove that the abrupt climate change is responsible for the collapse of old buildings. For instance, in Oslo in 2006, an apartment built in the late 1880s fell apart due to the wet weather and frequent temperature changes [38].

A similar study undertaken in Norway [33] noticed that most structural damages in buildings were due to water and moisture. Recently, the undesirable impacts of wet materials on the quality of indoor air and the ensuing health problems have been widely discussed [33]. Dampness and moisture might accumulate in the building's structure through leaks in the roof, windows or piping, or due to the insufficient ventilation or moisture from the ground, which penetrates the building's structure by capillary movement. Long exposure to mold can lead to other respiratory problems, while more droughts and wildfires can result in more particulate air pollution such as by dust and smoke. The particulates from the air, which accumulate in the building, could affect the lungs and heart health. The related adverse health effects vary from irritation of the respiratory system and mucous membranes and infections to permanent diseases such as allergies and asthma.

Flooding in Oxford, U.K, back in December 2008, for example, had effects on the building structure and caused health problems due to the increased humidity and mold growth. Increased precipitation and indoor humidity, which leads to mouldy interiors of buildings, has the potential to extensively increase the airborne exposure to fungi, including mycotoxin that produce microbial volatile organic compounds (MVOCs) [39]. Additionally, the release of chemicals and particles from building materials, bacteria, dust mites and other pests were found to increase with dampness, which can be allergenic in the indoor environment of the buildings [40]. In fact, faster growth of micro-organisms at higher germination power rates occurs at higher precipitation and temperature. This affects the species of microorganism growth, which may result in enhancement of more significant aesthetical damage on building materials [41].

Other phenomena such as summer heat waves has led to the increased in usage of air conditioners, which produce a cycle of additional energy consumption and contribute to global warming even further. The main climatic variables that determine the amount of energy required for air conditioning are solar radiation, outside air temperature, wind, rain and night sky radiation. The increased usage of air conditioning and fans necessitated by the rise in temperatures mostly leads to higher radon concentrations ensuing from decreased air exchange rates, particularly for tightly sealed buildings. The usage of air conditioning in closed buildings results in higher radon concentrations. The use of forced air by HVAC systems tends to reduce the stratification of radon between floors, thus increasing the radon concentrations on the upper floor where the occupants spend most of their time [42]. In addition, higher internal temperatures will increase the release of solvents and other pollutants from building materials and furnishings into the air. For instance, higher temperatures in the walls and cavities of buildings will increase the release of formaldehyde into the internal building space [43].

Likewise, long exposure to Ultraviolet (UV) radiation will also damage the building materials, such as plastics, paint and coatings such as specific hydrophobic and antigraffiti coatings, rubber products, wood and paper. Moreover, escalating amounts of plastic usage in building construction will also add to the plastic degradation problems [38]. Higher temperatures in combination with longer exposure to UV radiation may also expedite the degradation of roofing materials as roof materials are exposed to wind, rain, snow, hail, sunlight and temperature swings. Besides, higher temperature and annual precipitation influenced the conservation and durability of building materials. At the same time, high precipitation during winter will possibly result in more intense damage of the building materials due to frost [41].

4.2. Impacts of climate change on traditional HVAC systems in buildings

At present, most of the buildings in Europe opt to use natural ventilation and do not implement the electricity-using cooling appliances such as central air conditioning units and ventilators as an effort to reduce environmental and cost impacts [44]. However, this is gradually changing. Recently, energy consumption related to heating, ventilation and air conditioning (HVAC) have been increasing throughout Europe [17]. As the temperatures continue to rise, the cooling potential of natural ventilation has decreased. Thereby, the demand for space cooling during summer will rise due to the increase in internal temperature during summer heat waves. One of the energy requirement studies carried out in Athens, Greece indicated that the energy demands by the 2080s will rise by 30% during July and August [45]. Humphreys [48] in his study proved that people's comfort temperature in a free-running building has a strong linear relationship with the average outdoor temperature. This study demonstrated a strong relationship of people's expectation and knowledge about the indoor climate according to the outdoor climate variability. Thus, the increased in temperature will definitely affect the occupant comfort in the future.

Back in 1994, only 10% of the U.K.'s large buildings used air conditioning [46]. Currently, about a quarter of the UK's large buildings are estimated to have air conditioning and by 2020, this percentage is projected to rise up to 40% [49]. However, most of the buildings that were constructed before 1990 are naturally ventilated and has been proven to function poorly during summer heat waves [50]. This has escalated the urgency for the U.K. government to have a proper climate change weather file to assess the building performance. The prevalent trend of using glass facades on 'sealed' buildings has increased the risk of overheating and the reliance on energy intensive mechanical cooling systems in London's buildings. Furthermore, the increase in average summer temperatures of 0.73 °C per decade over the

past 30 years in London has also increased the risk of internal overheating [47]. The projected rise in both average and extreme temperatures will make London's buildings more uncomfortable, more expensive to operate due to high cooling energy costs and potentially dangerous to the occupant's health due to the high internal temperatures in poorly ventilated offices. These changes could result in productivity reduction, the need for retrofitting mechanical systems ventilation and depreciation of property values [47]. In addition, climatic variability will also affect the comfort and performance of building technical services due to the inconsistent power outages and quality, prolonged cold and rainy seasons, flooding, intense heat waves and winter storms [12]. Jentsch et al. [51] in their study came to the conclusion that appropriate actions such as usage of thermal mass, external solar shading and well designed ventilation strategies such as night cooling can keep the naturally ventilated buildings more comfortable during hot weather. All of these are required to ensure that naturally ventilated buildings in the U.K. and other countries can perform well during extreme weather events.

In a different study conducted in Iran by Delfani et al. [52], the increased in outdoor dry and wet bulb temperature together with moisture content in the air have caused the greenhouse effects to intensify. In addition, the latent heat gain and humidity content of the outdoor air during the summer season has also risen, thus causing buildings to increase their cooling load. Under these conditions, better HVAC equipment is needed for dehumidification of air in order to achieve acceptable comfort conditions [52]. The rise in humidity level due to the changes in wet bulb temperature has caused the direct evaporative coolers used to cool buildings incapable of achieving the appropriate comfort conditions in the humid climate, thus the implementation of high consumption chillers has become necessary [52].

In the same study, findings showed that the cooling equipment performance depends on the humidity and outdoor temperature. He concluded that the cooling devices' performances in a building are strongly affected by the changes in climate. The wet bulb temperature (WBT) and wet bulb depression (WBD) decrease drastically due to the change in outdoor moisture content as a result of climate change. For 1% rise in outdoor design conditions of hot seasons, the DBT has increased from 36.96 °C in 1967–1976 to 37.23 °C in 1997–2006, while the WBT has increased from 18.66 °C to 21.97 °C, thus affecting the efficiency of cooling devices. Thereby, the cooling demands during this period will likely increase due to the increase of WBT.

In Hong Kong, a study by Lam et al. [53] found a fundamental trend of the temperature increase in recent years, particularly in the last ten years. During 1961–1970, the DBT has increased by 0.4 °C while the WBT has increased by 0.5 °C. Investigations on seasonal factors found that the temperature increases happen during mid season and winter due to warmer winter periods. For instance, the DBT during the 10-year period rose by 0.1, 0.6 and 0.3 °C in summer, winter and seasons between correspondingly. In contrast with Delfani et al. [52], this study indicated that there will be no significant impacts on energy use, particularly in cooling, due to the temperature increase in subtropical Hong Kong. However, this study has not included the global warming effects during the summer period in the subtropical climate, and the existing design should be analyzed using current weather data to evaluate the effects on building energy consumption.

4.3. Impacts of climate change on heating and cooling energy consumption

The most apparent and significant implications of climatic variability on electricity usage in buildings are the effects on the cooling and heating energy consumption. Numerous studies have been conducted to predict commercial building energy consumption. Currently, increasing demand for appropriate thermal comfort during cold winter and hot summer is leading to the increase in building energy consumption [54,55]. Previous studies have discovered that there is an important trend of the temperature increase over the past few years resulting in decrease in comfort in winter and further discomfort in hot summer [45,48]. The methodology used to determine the changing patterns in heating and cooling demand is traditionally established on a formal relationship based on changes in degree-days, the energy requirement prior to cooling and heating, and expected changes in cooling market penetration. The location of the country strongly affects the number of heating degree-days. Typically, the number of heating degree-days of a country situated far from the equator is greater than its cooling degree-days.

Many studies have predicted climate change effects on energy requirements. A study conducted by Belzer et al. [56] determined the impacts of temperature variability and building features on energy consumption in large buildings using the detailed Commercial Building Energy Consumption Survey (CBECS) data on the United States (US) commercial buildings. The Belzer model projected a decline in yearly energy needs for heating and a rise in annual cooling energy demands. In addition, Sheppard et al. [57,58] carried out a separate study to analyze the consequence of the climate shift on energy consumption in large buildings in the Sydney region. In this study, it was estimated that the energy consumption would increase by 10–17%, mostly due to the increase in carbon emissions to the atmosphere.

In another study conducted in the U.S., Considine et al. [59] found that the climate variability had a strong impact on natural gas and electricity demands. In a follow up study [60], he studied the implications of weather variations on monthly energy requirements among different users and concluded that energy demand in all sectors is vulnerable to variability in degree-days. He also found that the elasticity of heating degree-days have significant effects on energy use and impacts of emissions as the elasticity of heating degree days is greater than the elasticity of cooling degree days. However, the just mentioned study does not focus on the potential climate change implications on user demand.

Another study carried out by Frank [61] concluded that office building cooling energy will rise by up to 1050% as the number of cooling days increases. The calculations demonstrated that the building energy demands for space heating in all climate settings are highly affected by the thermal insulation level. Generally, the life span of buildings in Switzerland is approximately a century and historically, engineers and architects have presumed that the outdoor climate would not change according to the statistical data compiled over 30 years ago. He suggested that this particular approach under the Swiss SIA Standards [62] has to be reassessed and the building weather design standards, particularly during hot summers, have to be reevaluated. However, this study was not entirely adequate since only a few building parameters were systematically analyzed.

One of the studies carried out in New Zealand [67] stressed that the climate change risk plans and rating tools are crucial for future revisions and assessment of building codes. Generally, most studies on energy demand to date have applied the cooling and heating degree-day approach [66,68]. However, only a few studies have employed detailed numerical simulation modeling [69]. Most of these studies predict a drastic increase in the cooling energy requirements, which compensates for the huge decrease in heating energy requirements.

Christenson et al. [63] in their study investigated the effects of climate change on building design specifications to determine the energy required for heating and cooling. They found that in years

Table 1
Climate change impacts on heating and cooling energy consumption.

Study: author(s), date and place	Change in energy consumption (%)	Temperature change (°C) and date for change
Rosenthal et al. [64], USA	Cooling: +15% Heating: −16%	1 °C (2010)
Belzer et al. [56], USA	Cooling: +53.9% or +9.0 − 13.8% Heating: −29.0 to −35%	3.9 °C or 1 °C (2030) 1 °C (2003)
Frank [61], Switzerland	Cooling: +1050%	4.4 °C (1984–2003)
Lam [53], Hong Kong		WBT + 0.5 °C (1961–1070) DBT + 0.4 °C (1961–1970)
Scott et al. [86], USA	Cooling: +9.4 −15% Heating: −5% to −24%	1 °C (2020) 1.7 °C median (2020)
Christenson et al., [63], Switzerland	Cooling: +50 −170%	At Cooling Degree Days (CDD) 18.3 °C threshold (1901–2003)
Huang [88], USA	Cooling: +17% +36% +53% Heating: −12% −22% −33%	 1.7 °C (2020) 3.4 °C (2050) 5.3 °C (2080) 1.3 °C (2020) 2.6 °C (2050) 4.1 °C (2080)
De Cian et al. [70], Italy	Electricity demand +1.17% (hot country) −0.21% (cold country)	For +1% rise in summer temperature
Radhi [75], UAE	Cooling degree days (CDD) +16–27% +22–42%	 2050 2100
Delfani et al. [52], Tehran		For +1% rise in outdoor temperature: WBT + from 18.66 °C (1967–1976) to 21.97 °C (1997–2006) DBT + from 36.96(1967–1976) to 37.23 °C (1997–2006) WBT +18.66 °C from (1967–1976) to 21.97 °C (1997–2006)

to come, energy required for heating in Switzerland would drop significantly depending on the magnitude of the temperature increase, building location and quality. In addition, the future relative decrease in heating energy use is predicted to outweigh the reduction in heating degree-days in buildings with high internal and solar gains. However, contrary to this, the potential cooling energy demand is expected to increase significantly from 50% to 170% between 1901 and 2003 based on cooling degree days at the 18.3 °C threshold. In the period of 1975 to 2085, the cooling degree-days are estimated to rise by 2100%. Findings from other study concurred that there will be more cooling degree-days compared to heating degree-days [74]. Thus, electricity demand related to heating and cooling will change, as more cooling and less heating is needed. Presently, nearly all countries in the world depend on electricity for space heating and cooling. The generally obvious trends of increases in cooling and declines in heating demand validate the results from earlier studies [56,64–66].

De Cian et al. [70] in their empirical study proposed that lower energy use is expected during the winter in colder countries such as Canada and Norway and higher energy use during summer and spring in hot countries such as Mexico. In mild countries such as Italy, the additional energy required during summer is evened out by the decline in demand for gas, oil products and coal in winter and spring. In colder countries, the elasticity of electricity requirements due to winter temperatures is −0.21, while in warmer countries, it is 1.17. This implied that the demand for electricity would increase by up to 1.17% in hot countries and decreased by up to 0.21% in colder countries for a 1% increase in summer temperature, which is similar to the conclusions from a previous study by Considine et al. [59]. A very similar study conducted by Eskekand et al. [71], which yielded the same results, concluded that the demand would change by 2 kW h per capita due to the variability in heating degree days, and by 8 kW h per capita in cooling degree days for a unit increase in temperature.

Meanwhile, Scott and Huang [72] in a current review of U.S. energy systems identified that energy consumption is subject to a 5% change for 1 °C increased in temperature. The same effects would also be experienced by Australia and New Zealand as reported by the IPCC. For instance, the demand for energy in New Zealand would increase by 3% for 1 °C increased in winter temperature. In addition, Mansur et al. [73] found that residential and commercial buildings will consume energy in the form of oil, gas and electricity due to warmer summers and cooler and wetter winters. They concluded that the climate change will decrease the usage of other fuels for heating and would likely raise the electricity consumption for cooling.

Radhi [75] in his study in UAE identified that there will be significant positive impacts on the heating degree-days and negative impacts on the cooling degree-days. The heating degree-days, particularly under scenario 4, will have a sharp drop, where the decrease reaches 100%, while the cooling degree-days will steadily rise up in the range of between 16% to 27% in 2050 and 22% to 42% in 2100. Related to this, a drastic change is expected in the proportion of energy consumption through air conditioning usage to attain acceptable comfort during the hot summer in Al-A in city. A different study that reached the same results was conducted by Jaber et al. [76], who found that electricity consumption in commercial buildings is comparatively high due to the usage of air conditioners and ventilation resulting from the hot and dry climate during the summer in Jordan. However, there are no data available related to certain or different types of commercial buildings' energy consumption and performance to date.

Overall, the impacts on heating and cooling requirements are obviously critical under the changing climate, and the findings are coherent throughout all studies in different seasons, periods and regions (Table 1).

4.4. Impacts of climate change on electrical peak demand and energy consumption in buildings

Many studies have been conducted regarding the climate change effects on energy consumption and peak demand. Nearly all the studies estimated the impacts based on the traditional approach by degree-days. All the studies showed a drastic increase in cooling energy demand and a sharp fall in heating energy demand. Sailor [77] and Rong and Smith [78] in their study on the effects of current and potential climate shifts, particularly on cooling and heating requirement in the U.S. demonstrated this clearly. Moreover, the results from Aebischer et al.'s [79] study also confirmed this by showing that the growth of cooling energy demand by 2035 under the changing climate will probably offset the decline in the heating energy demand. However, studies on climate variability in the dry and hot countries in the Middle East and the effects on HVAC systems have not specifically been conducted up to now [52].

According to one of the studies carried out in Australia, the erratic weather patterns are anticipated to have strong impacts on energy consumption, particularly on the electrical peak demand [80]. The cooling energy requirements are predicted to increase due to the warming climate and may subsequently offset the advantage of the heating energy savings [61,81]. BRANZ in a comprehensive study on the climate change effects of different building types in Australia stated that the ongoing climate change would strongly affect the energy consumption in buildings [82].

During hot summer days, the risk of demand not being met seems to be escalating due to the air conditioner usage in all cities worldwide [83]. Global warming increases the magnitude of peak demands, resulting in the need for additional generating capacity to be installed at considerable cost with uncertain implications on greenhouse emissions. The increase in air conditioner usage has increased the sensitivity of electricity demand to hot summer weather [83]. Mansur et al. [84] in their study disclosed that building electricity consumption would decline by about 3% for 1 °C rise in January temperatures. The warmer temperatures would have a strong impact on fuel oil consumption, as the fuel oil demand would increase by 12% per 1 °C increase. Warming is predicted to have the greatest impact on the heating degree-days in the countries where fuel oil is most dominant. In fact, most of the energy consumption of older vintage commercial buildings which use fuel oil, is more sensitive to temperature swings.

In a study conducted in Australia, Howden [80] found that the range of response of electricity demand to climate change is similar to that in the U.S. Also, in the U.S., for 3 °C increased in temperature, the average electricity demand will rise by 3.5 to 13% for tropical locations, 2.5 to 7% for temperate locations and decrease the demand by about 5% in cool locations [85]. Findings showed that the frequency and variability of intense weather events such as heat waves would have significant implications on the peak electricity demand for cooling.

Extreme warming is anticipated to raise the energy demand for space cooling in most countries that use electricity. Apparently, in most of the studies, the effect of the climate warming is not necessarily related to the humidity and temperature, given that the amount of the impacts is higher than the temperature shift [85]. Several studies predicted that increases in cooling demands in the long term would outweigh the decreases in heating as the temperature continues to increase [56]. These impacts, however, are not necessarily discovered in studies on the climate change predicted in the U.S. during the 21st century.

Other studies conducted in commercial buildings have demonstrated that commercial buildings are less responsive to temperature changes for space cooling when compared to residential buildings. Related to this, Rosenthal et al. [64] stated that the commercial buildings' cooling increased by 15% while the residential buildings' cooling increased by up to 20% per 1 °C increase. The same applies to commercial buildings' cooling requirements in Scott et al.'s [86] study: a 15% increase per 1 °C change.

Hadley et al. [87] conducted a study using the Degree-Das National Energy Modeling System (DD-NEMS) energy model. This model provided an overall estimation of energy demand, supply and price response to a market model. However, the drawback of this model is that it only predicts until the year 2025, when the climate changes are about to influence the energy requirements directly. This study suggested that the rise in cooling demand would offset the decline in heating demand. Nevertheless, the rise in cooling demand was predicted to dominate elsewhere in the country.

Huang et al. [88] took their study in a new direction and found that the climate variability effects on energy requirements in large buildings were highly dependent on the building types and climate change scenarios. The simulations illustrated a 9.2% decline per 1 °C change in energy consumed for heating. Huang's study showed that energy demand in colder regions would drastically decline compared to that in temperate regions. In 2020, he predicted a drastic rise in cooling energy consumption, a 10% increase per 1 °C change. According to the analysis, the electric energy use is predicted to increase by 10% to 15% in the future. Additionally, based on the econometric study, the usage of electricity will also increase due to the variability in electricity consumption such as lighting and plug loads.

In the same study, Huang et al. [88] addressed that by 2020, the site energy use in U.S. building stock would decrease by 7% due to the 1% decrease in primary energy corresponding to the losses in electricity during generation and transmission. The study estimated that the demand for cooling in commercial building would increase while in contrary, the demand for heating would decline due to less exposure to outdoor conditions and their large internal heat gains. Accordingly, the same trend is expected in other building types such as malls and hotels. However, this study does not consider the socioeconomic factors of climate change adaptation strategies.

It is projected that in 2050 and 2080, newer sealed buildings will need more cooling and less heating compared with older existing buildings due to the impacts of further increases in temperature. The cooling loads are predicted to rise by 85% in 2050, while in contrast, the heating load is predicted to decrease by 28% as a result of global warming across all building types and climate change scenarios. Meanwhile, in 2080, the heating requirements have been estimated to decline by about 45%, and the cooling requirements to increase by about 165%. Related to this, the ratio of cooling to heating energy consumption in 2080 is approximately 60% in site energy.

Most studies to date on building energy demand for cooling and heating have been based on simplified analyses using the constant rise in annual average temperature or changes in cooling or heating degree-days. Results from these studies appeared to be insufficient and imprecise to illustrate the climate change implications on building energy technologies. For instance, the insufficient information on solar radiation, humidity and diurnal temperature changes makes it hard to evaluate the implications of climate variability on certain types of HVAC system usage, such as evaporative cooling, night cooling, natural ventilation, radiant slab cooling and other equipments.

Xu et al. [89] in their study in California take a step further and develop more detailed hourly weather data and models to investigate the California specific impact of global warming on buildings' energy consumption. This study utilized the archived General Circulation Model (GCM) projections and statistically downscaled these data to the site scale to be used as an input for building heating and cooling simulations. They concluded that the electricity consumption for cooling would rise by more than 50% over the next 100 years. The cooling electricity consumption will rise by about 25% for the A2 scenario, and between 2% to 8% for all three IPCC carbon scenarios analyzed in this study. Generally, cooling energy consumption will rise while the heating energy will decline for all kinds of buildings. However, small buildings are more sensitive to climate change than larger buildings because the percentage of envelope heat gain and heat loss of small buildings is greater compared to the large buildings. In addition, the peak electricity demand will rise in certain types of buildings that are more sensitive to climate change. Nevertheless, this study is a preliminary step of applying future hourly weather data to predict the effects of global warming. A follow up study should be conducted to address the implications of climate change on existing buildings as most of the buildings were built according to weather files in the past.

4.5. Climate change impacts on buildings' carbon emissions

As the observed atmospheric carbon dioxide increases, the near surface air temperature is predicted to increase as well. Of all the impacts of warming, the most important and well-studied is the impact of increasing greenhouse gases emissions due to the changing pattern of energy demand, particularly for cooling and heating in buildings. Generally, the climatic variability has strong impacts on energy consumption in commercial buildings. Energy demand and consumption in a building depend on the building activities, total floor space, building shell efficiency and heating and cooling capacity [87].

From the viewpoint of emissions, temperature swing will strongly affect the primary energy losses, especially during electricity generation. As more cooling is needed compared to heating, primary energy will change by a different amount compared to the energy demand. The primary energy will differ from the energy demand as electricity is consumed for space cooling compared to heating. The rise in cooling demand due to the temperature rise would outweigh the decline in heating demand. Thus, as cooling is less energy efficient than heating, the changing pattern in energy use will strongly affect the fossil-fuel carbon emission.

In a study conducted by Hadley et al. [87], they predicted that the 1.2 °C scenarios would led to a cumulative (2003–2025) energy rise of 1.09 quadrillion Btu for cooling/heating requirements. For a 3.4 °C scenario, the decreased heating requirement would produce a cumulative (2003–2025) heating or cooling energy reduction of 0.82 quads due to temperature increases during the winter months. Nevertheless, in both scenarios, the rise in carbon emissions from electricity generation offsets the carbon emission decreases due to the reduced in heating requirements.

Another study by Isaac and van Vuuren [90] projects the world's energy heating demand will rise until 2030, and later stabilize for the scenario applied. In contrast, the energy required for cooling purposes is predicted to increase dramatically between 2000 and 2100, mostly due to the increase in income. The carbon emissions associated with heating and cooling rise to 0.8 Gt C and 2.2 Gt C in 2000 and 2100, respectively. Note that approximately 12% of the total of carbon are emitted into the atmosphere due to energy use. In addition, the global carbon emissions in the reference scenarios will increase in 2100, where the emissions increase to more than 0.3 Gt C under the changing climate due to the changing patterns in energy demand. The rise in emissions is due to the fact that the factor of emissions for electricity is considerably higher compared to fuels. This will definitely affect India and China due to the increased use of air conditioning as it contributes to global warming even further. Currently, in India, total emissions rise steadily with the increased usage of air conditioners. Somewhat in contrast, in China, the initial rise was much more drastic, but will stabilize later on due to the earlier implementation of air conditioners in China because of higher incomes and larger prospects of decrease in heating energy demand. In other parts of Asia, the study indicates a clear increase in emissions due to the temperature rise while in the U.S., lower emissions are expected in agreement with the findings of the United States Climate Change Science Programs (USCCSP) (2006).

5. Conclusions

A comprehensive literature review on the climate change impacts on buildings and their technical services in the tropics is successfully carried out. This review implies that the incremental warming has seriously affected the performance and sustainability of buildings, especially in terms of energy consumption. Generally, the tropical region will experience an increase in energy demand, while temperate regions will experience a decrease. Moreover, the literature review reveals that the climate variability will strongly influence the energy demands of buildings, particularly in heating and cooling, and the findings are coherent across studies focusing on different seasons, periods and countries. Nonetheless, the magnitude of the impacts differs throughout studies due to climate variations. Hence, the building sector has to ensure that the current and future buildings are able to adapt to local climate changes in order to minimize the potentially destructive impacts and increase the viability and sustainability of the buildings in the future.

Based on the present study, there will be an increase in cooling demand and decline in heating demand in regions where there is a projected rise in temperature. Therefore, the buildings' energy consumption and carbon emissions are inevitably expected to rise dramatically during its operational phase, thus increasing its operational and maintenance cost. Generally, the most important impacts of the climate shift on buildings and their technical services are the changing pattern in cooling and heating demand, energy consumption and peak demand, carbon emissions and physical structures.

Up to date, only a few regional studies on the impacts in tropical countries have been carried out. Literature reviews on the climate change effects on buildings and their technical services in tropical regions such as Malaysia, Southern Thailand, Brunei, Indonesia and Singapore are especially rare. The available informations are clearly inadequate, and the lack of significant data make it hard for these countries to perceive and estimate the magnitude of the impacts on the building sector in these regions. In that respect, the convincing empirical research study and inclusive assessment of the impacts of climate change events on these countries need to be performed specifically in order for these countries to be able to adapt to the severe climate change impacts anticipated in years to come. In addition, the increasing requirements for cooling during hot periods, buildings' carbon emissions, as well as extreme weather events that cause damage to the building structure should be taken into consideration during the design phase in the future with the aim to reduce future buildings' energy consumption and greenhouse gas emissions.

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